

PULSATION OF LATE B-TYPE STARS

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Three of the brightest stars in the Pleiades, Alcyone, Maia and Taygeta, were observed repeatedly for radial velocity throughout the course of one night, 25 October 1976. All three stars were discovered to be pulsating with periods of a few hours. Analysis of all published radial velocities for each star, covering more than 70 years and approximately 100,000 cycles, has established the value of the periods to eight decimal places, and demonstrated constancy of the periods. However, amplitudes of the radial velocity variations change over long time intervals, and changes in spectral line intensities are observed in phase with the pulsation. All three stars may also be members of binary systems.

INTRODUCTION

Three classes of short period variable stars have been intensively studied to date -- RR Lyrae stars, Beta Cephei stars and Delta Scuti stars. The existence of stars exhibiting short period variability but located on the H-R diagram between these classes seems virtually unknown.

Originally, Struve (1955) postulated an intermediate class of such stars which he designated as the Maia Sequence. This sequence was defined by Maia

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(B7 III) at the bright end and by γ UMi (A3 II-III) at the faint end. No other stars were ever included in the sequence and Struve (Struve et al. 1957) later abandoned the sequence when he concluded that Maia did not show short period variability in either light or radial velocity. This investigation demonstrates that his conclusion is incorrect, at least with respect to radial velocity.

The existence of other stars quite similar to γ UMi such as Vega (Beardsley 1969) and θ Vir (Beardsley and Zizka 1977) suggests that the so-called Maia Sequence may not be invalid. Consequently, three bright member stars in the Pleiades were sampled by the authors at Kitt Peak National Observatory in a search for short period variation in radial velocity. The instrument used was the Coude' Feed (0.9m) telescope, dispersion 17 \AA mm^{-1} . The Pleiades were chosen since it seemed likely that the suspect nature of Maia might properly implicate other Pleiades members as well. The three stars in the sample were Alcyone, Maia, and Taygeta.

All survey observations were obtained on the night of 25 October 1976. Baked 127 emulsion was employed together with suitable blocking filters. Since these stars are bright exposure times never exceeded 10 minutes and the spectra were all well exposed in the spectral region $\lambda\lambda 3700 - 4400 \text{ \AA}$. The plates were measured on a Grant engine with oscilloscopic display. Most lines, including hydrogen, displayed near Lorentzian profiles facilitating accurate setting. Every possible spectral line was measured except for obvious blends. Final velocities are based upon an average of about 20 stellar lines in the case of Maia, 15 in the case of Taygeta and 10 in the case of Alcyone. For each plate approximately 40 Fe-comparison lines were measured. The final radial velocity reduction employed a polynomial fit to

the comparison lines using a computer program entitled RSPEC (Worek 1977).

DETAILED SURVEY RESULTS

a) Alcyone, - Alcyone (25 Tauri, HD 23630) is the brightest member of the Pleiades cluster. Nothing of particular significance has been reported about this star. Radial-velocity observations show a scatter not considered unusual for a B-type star having fairly broad lines. The five radial velocities obtained on the survey night are plotted in Figure 1. The evidence suggests, though not convincingly, that a period of 0.27 day may exist. Early Allegheny Observatory observations (Beardsley 1969) were found to corroborate the 0.27-day period and it was possible to improve the period until all observations were included. The final period is 0.27118746 day,

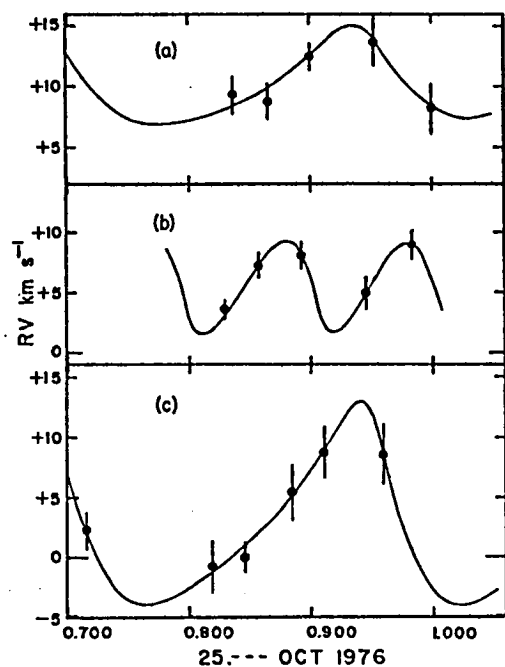


Fig. 1.--A plot of all the survey radial velocities obtained on the night of 25 October 1976. (a) denotes Alcyone, (b) denotes Maia, and (c) denotes Taygeta. Error bars represent standard error of the mean.

and Figure 2 represents a phase plot of all radial velocity observations since 1903 based upon this period. In forming this plot no systematic

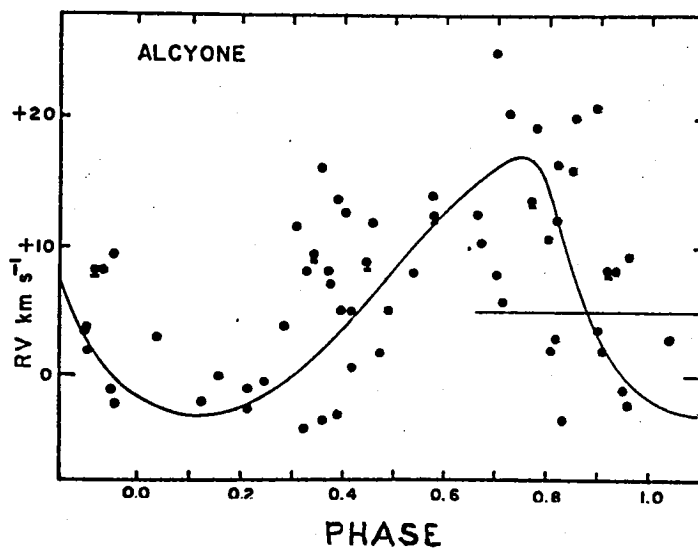


Fig. 2.--A phase plot of all published radial velocities since 1903 based upon a period of 0.27118746 day and beginning at JD2416418.475. Nearly 100,000 cycles are represented.

observatory corrections have been applied, obvious variations in amplitude over many years time have been neglected as well as possible variation of the systemic velocity due to binary motion with an as yet undetermined period. All act to introduce the observed scatter. Evidence of a possible standstill in the pulsation is suggested by the increased scatter at phase 0.4.

b) Maia, - Maia (20 Tauri, HD 23408), the fourth brightest cluster member, was originally suspected of pulsation-type radial velocity variation many years ago by Henroteau (1921) who suggested correctly that the period might be close to 2 hours. Radial velocity variation had previously been detected by Adams (1904) and studied intensively by Merrill (1914). Merrill was looking for binary motion but could reach no conclusion due to the unsuspected presence of the pulsation. Henroteau was searching for very

short-period binary motion and concluded that perhaps pulsation was present instead. Since each complicated the search for the other, it was not possible to define either. Struve et al. (1957) searched carefully for pulsation. Why it was not detected is unclear since the individual radial velocities remain unpublished. However, variations in the spectral line widths were detected which also suggested a period of about 2 hours.

Measurement of the six survey spectra obtained on the night of 25 October 1976 for radial velocity convincingly showed that pulsation was present with a period of about 0.10 day. These measures are also plotted in Figure 1. Figure 3 presents the observations of Henroteau for two of his five full-night series. Clearly apparent is the presence of the pulsation

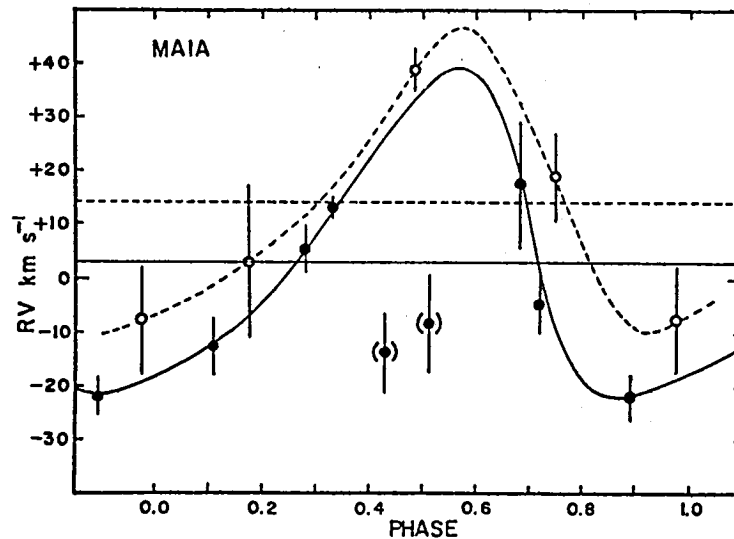


Fig. 3.--A phase plot of the published radial velocities by Henroteau obtained on two separate nights. Filled circles represent observations obtained on the night of 16 December 1919 and open circles the night of 16 August 1920. Note the strong shift in systemic velocity due to binary motion. The two rejected velocities at phases 0.4 and 0.5 are possibly the result of blending of separate shock wave component lines, one very positive and one very negative. A similar occurrence has been observed by the authors at about this phase for Taygeta.

and a variation in the systemic velocity as well, undoubtedly caused by binary motion. Note also the large variation in the pulsation amplitude between the 1919-20 and the 1976 epochs when compared with Figure 1. The period of pulsation has been determined to be 0.1032967 day. It has not been possible again to define the period of the binary motion. Consequently the velocities have not been combined into a single pulsation phase plot.

Changes in line widths have been noted in the Kitt Peak survey spectra as well as possible changes in excitation temperature. These changes vary in phase with the period with low excitation lines of FeII strong at times and high excitation lines of OII possibly present at other times. A quantitative study of this phenomenon is planned for a future time utilizing more suitable spectra obtained for this purpose.

c) Taygeta, - Taygeta (19 Tauri, HD 23338), the sixth brightest member of the cluster, has been utilized by Petrie (1953) as a standard star for a determination of B-star spectral-line wavelengths. Later, Abt (1965) suspected the presence of binary motion and presented tentative spectroscopic orbital elements but with expressed reservations. Six radial velocities were obtained for the survey night and a convincing pulsation variation was found to exist. These are also plotted in Figure 1 and indicate a period close to 0.27 day. A study of all published radial velocities suggests that the pulsation period is 0.2707795 day. A phase plot of the velocities based upon this period is presented in Figure 4. Again a variation in the systemic velocity due to apparent binary motion introduces scatter, and once again it is not possible to remove the binary motion until more reliable orbital elements can be obtained.

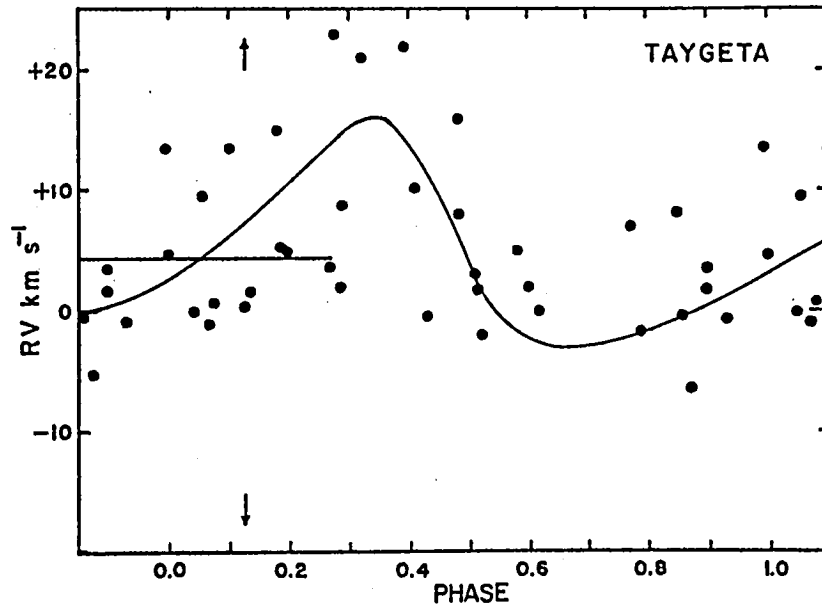


Fig. 4.--A phase plot of all published radial velocities of Taygeta since 1904 based on a period of 0.2707795 day beginning at JD2416503.475. The arrows refer to an observation obtained at the Allegheny on 12 October 1909. The lines on this plate appear double and possibly represent different shock wave components. The measured velocities are -49.6 km s^{-1} and 60.7 km s^{-1} .

Allegheny Observatory plate 3116 of this star, obtained on 12 October 1909 was originally measured for radial velocity by Stephen Thaw, and from this measurement a velocity of 40.5 km s^{-1} was derived (Beardsley 1969). Remeasurement of this plate by the authors revealed that the lines were in fact double, the velocities for which are presented in the figure caption above. The phase of this plate occurs at that point on the pulsation curve where a standstill might be suspected and the doubling may represent different shock wave components.

As in Maia, pronounced changes in line intensities and excitation temperature occur for this star in correlation with pulsation phase. These changes embody also the appearance and disappearance of low excitation Fe II

and high excitation O II lines and will be the subject of a future investigation.

CONCLUSION

The foregoing results, which are both new and unanticipated, suggest strongly that all three stars in the sample -- Alcyone, Maia and Taygeta, representing the brightest cluster members -- pulsate with well defined periods, constant over 100,000 cycles, and which have been determined to eight decimal places. The data also suggest that variations in velocity amplitude occur, and that spectral variations occur in phase with the velocity variation. Furthermore, these three stars are possible members of binary systems.

Note that in Figure 1 the peak velocity for both Alcyone and Taygeta occurs at nearly the same time. This coincidence raises a possibility that instrumental error has affected the velocities. During an observing run at Kitt Peak Observatory in March 1977 a strong series of Standard Velocity Star observations was obtained over the course of several nights. Results indicate that systematic differences in radial velocity were noted from night to night but that during each night these differences remained constant. This phenomenon will be investigated further but the authors are convinced that variation in velocity observed throughout the course of a single night may be considered real. Also the differing amplitude of velocity variation for each star serves to substantiate the non-instrumental nature of the results.

The implications of these results are many. For example: does the Pleiades cluster possess a very blue pulsation sequence, and if so does

there exist a cut-off position in the Cluster HR diagram or does this sequence blend into the δ Scuti region (see Breger 1975)? Do other clusters show this phenomenon as well and to what extent do early type field stars, excluding β Cepheids, also pulsate? Is this pulsation correlated with low rotation (most stars discussed here appear to have sharp lines) and is this pulsation correlated with cessation of hydrogen burning and recent evolution from the Main Sequence? Does the 25% helium content criterion for the onset of pulsation in the case of δ Scuti stars apply to these stars as well?

These are but a few possible questions these measures raise, but they suffice to indicate that the above pulsation discoveries point to an important new direction in observational astrophysics. Although no conclusive evidence is available as yet pro or con, it seems possible from the evidence presented that most, if not all, B-stars may be subject to pulsation. These observations will be continued.

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Discussion

Schmidt: What are the spectral types of these stars?

Beardsley: Alcyone is a B6 giant, Maia is a B7 giant, and Taygeta is a B7 giant. Maia, of course, has a very sharp-lined spectrum and is very unusual, even for a giant.

A. Cox: Did you try to construct a periodogram to see if there were any other periods? I gather you based your period on your modern observations, and phased all the earlier observations. Did you try to see what other periods might exist?

Beardsley: No. These observations are much too embryonic to get involved in anything like that. We have to continue the observations. But obviously, we have a "standstill," so there must be something else involved.

Wesselink: I presume that all these stars are members of the Pleiades cluster, so you have a check on the gamma velocity of all your curves.

Beardsley: Yes, but one of the problems coming up at the next IAU meeting will be the question of standard velocity stars for B type stars. And I think the stars that ought to be proposed are the Pleiades stars. But to do so, we'll have to model out the pulsations and the binary motion, and then we can get very accurate radial velocities for the cluster itself.

Wesselink: In any case, the stars you have shown have the same gamma velocity.

Beardsley: Yes, very close. But I would say that right now our knowledge of the cluster velocity is very poor, on the basis of this work.